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**FRICITION AND WEAR OF SELECTED METALS
AND OF CARBONS IN LIQUID NATURAL GAS**

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16. Abstract <p>Friction and wear experiments were conducted with hemispherically tipped (4.76-mm radius) rider specimens in sliding contact with a rotating disk submerged in liquid natural gas (LNG). The program included metal combinations and carbon-metal combinations. These experiments revealed that the metal combinations were not lubricated by the LNG. Carbons had much lower wear in LNG than in liquid hydrogen or in liquid nitrogen. (Wear of carbon in liquid hydrogen was 100 times that in LNG.) The friction coefficients obtained in LNG (0.6 for metal-metal and 0.2 for carbon-metal) are similar to those obtained in liquid hydrogen.</p>					
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CARBONS IN LIQUID NATURAL GAS

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SUMMARY

Sliding contact experiments conducted in liquid natural gas (LNG) revealed that metals (304 stainless steel on 304 stainless steel, 440C stainless steel on 440C stainless steel, and 52100 carbon steel on 52100 carbon steel) exhibited high friction coefficients and high wear rates. All metal combinations showed severe galling and welding; results were comparable with those obtained in liquid nitrogen and in liquid hydrogen.

Included in this program were (1) two grades of mechanical carbon, (2) a vitreous carbon, and (3) a pyrolytic carbon. These carbons were run against 304 or 440C steel. All carbons formed a faint transfer film on the mating surface; the wear rate in LNG was less than 1 percent of the wear rate obtained in liquid nitrogen or in liquid hydrogen. The friction coefficient in LNG were similar to that obtained in liquid nitrogen and in liquid hydrogen (about 0.2).

These experiments were run using a hemispherically tipped rider (4.76-mm radius) sliding on the flat surface of a disk submerged in LNG. Sliding velocity was 12.4 meters per second with a load of 1 kilogram.

INTRODUCTION

The potential use of liquid natural gas (LNG) and of liquid methane as a fuel for advanced aircraft as well as for industrial heating applications suggests the importance of determining the lubricating properties of materials that are in sliding contact in these liquids. The advanced aircraft turbopumps and their associated ground support equipment (e.g., compressors and pumps) require seals and bearings that can operate in their fuels for long periods of time (ref. 1). It is also necessary to have pumping equipment for transferring LNG from one vehicle to another (e.g., ship to truck). This equipment also requires bearings and seals for safe and efficient operation.

Experience with various materials combinations in cryogenic fluids such as liquid nitrogen and liquid hydrogen has indicated that these two cryogenic fluids are not boundary lubricants (refs. 2 to 5). However, since LNG is a mixture of hydrocarbons, predominately CH_4 , it would be expected that it might provide some degree of lubrication.

Lubrication studies (ref. 6) show that the friction coefficient of steel on steel sliding in various hydrocarbons decreases with increasing molecular weight. Hardy (ref. 6) also mentions that mixtures of two hydrocarbons can show friction coefficients that are lower than for either of the hydrocarbons alone. It might, therefore, be expected that LNG could lubricate better than liquid methane alone. Work by Savage (refs. 7 and 8) shows the importance of the graphite transfer film in reducing wear. Also reported in reference 6, was the beneficial influence of several hydrocarbons on the wear of carbon brush materials. From the results reported in references 7 and 8, it would be expected that the wear of carbon materials might be improved by the presence of the LNG. Reference 6 indicates that the friction coefficient of metals might be high (greater than 0.3) in the LNG.

The objective of this investigation was to determine if liquid natural gas had lubricating properties typical of higher molecular-weight lubricating hydrocarbons with regard to metal combinations or carbon-metal combinations and to select useful material combinations from the results obtained.

Hemispherically tipped rider specimens were run in sliding contact against a rotating disk submerged in liquid natural gas. Data were obtained with a sliding velocity of 12.4 meters per second and a load of 1 kilogram. The data presented are typical of those obtained with two to four identical runs.

APPARATUS AND PROCEDURE FOR FRICTION AND WEAR STUDIES

The apparatus used in the friction and wear studies is shown in figure 1. The basic elements consisted of a hemispherically tipped 4.76-millimeter-radius rider specimen held in sliding contact with the lower flat surface of a 63.5-millimeter-diameter rotating disk. The experiments were conducted with specimens completely submerged in liquid natural gas. The drive shaft supporting the disk specimen was driven by a hydraulic motor through a 6:1 speed increaser, and it provided a sliding velocity of 12.4 meters per second (4100 rpm) for the data reported herein.

The rider specimen was loaded to 1 kilogram against the rotating disk specimen by a helium-pressurized bellows assembly. The cryogenic fluid was transferred to the test chamber through a closed system. The storage vessel was pressurized to transfer the liquid and to maintain the liquid level.

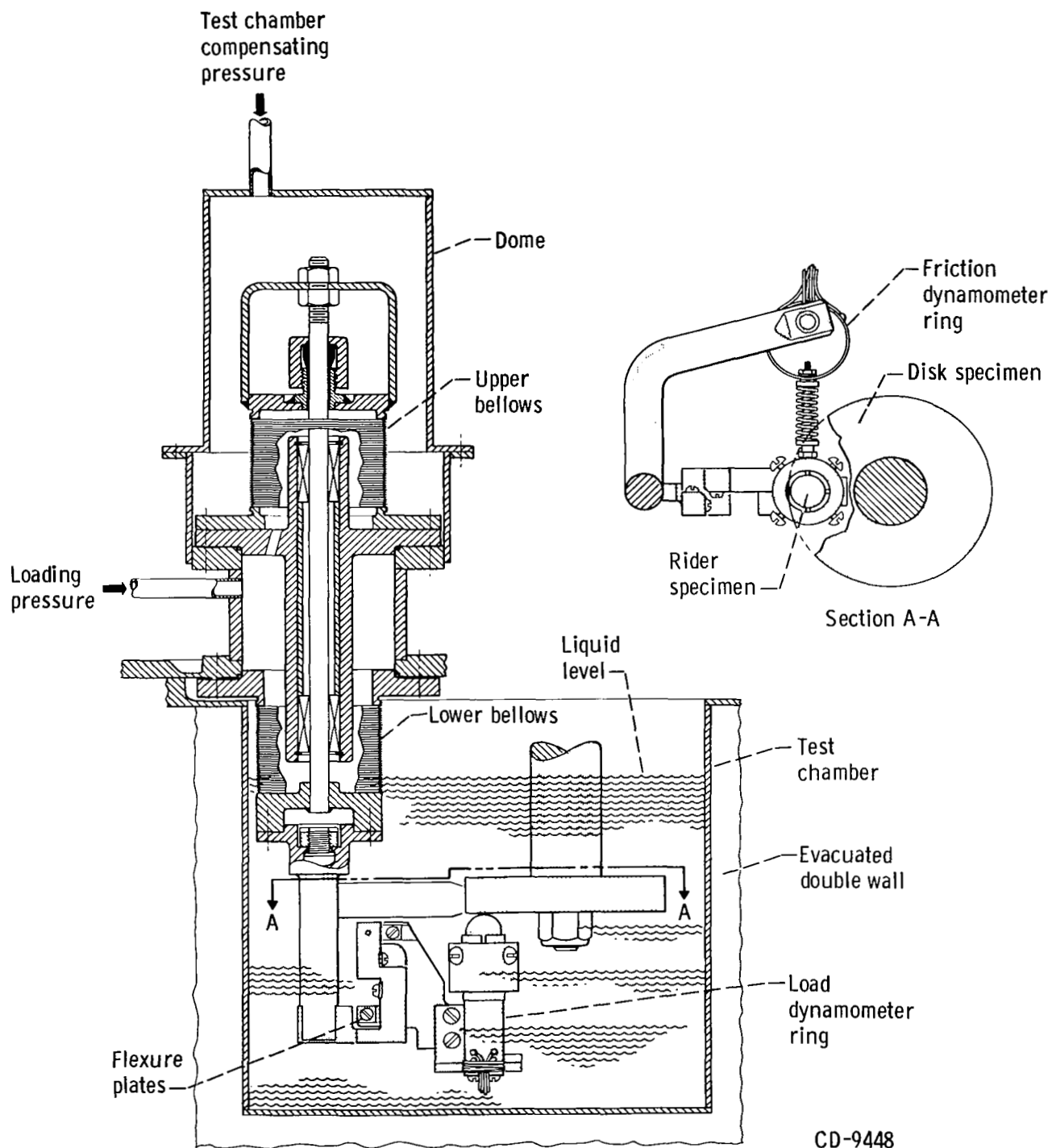


Figure 1. - Cryogenic fuel friction apparatus with specimen loading system.

The test chamber was cleaned with 90 percent ethyl alcohol before each run. After cleaning and the installation of the specimens, the test chamber was closed, purged for 15 minutes with helium gas, and then filled with the liquid natural gas. After the test chamber was full and the liquid boiling stabilized, the rider specimen was loaded against the rotating disk. The duration of most runs was 1/2 hour (for convenience). The materials that wore rapidly were run for a shorter time.

The frictional force and the load were measured by strain-gage dynamometer rings. A dual-channel recording potentiometer was used as a strain indicator. The wear of the rider specimen was determined by measuring the wear-scar diameter and calculating the wear volume. The vertical position of the rider specimen (referenced to the disk) was measured by a linearly variable differential transformer (LVDT) measuring system, the output of which was continuously recorded. The LVDT was used to monitor the wear during the run.

The disk specimen preparation was as follows: The surfaces were

- (1) Finished-ground and lapped to 5×10^{-2} micrometer rms (2 μ in. rms)
- (2) Scrubbed with moist levigated alumina
- (3) Washed in tap water
- (4) Washed in distilled water and air dried.

The carbon riders were submerged in 90-percent ethyl alcohol and then ultrasonically cleaned. Specimens were then evacuated (50 to 100 torr) for 24 hours and back-

TABLE I. - ROOM TEMPERATURE PHYSICAL PROPERTIES
OF THE MATERIALS STUDIED

[Source, manufacturer's literature.]

Metal	Hardness
304 stainless steel	80 Rockwell B
440C stainless steel	56 Rockwell C
52100 carbon steel	60 Rockwell C

Carbon	Specific gravity	Scleroscope hardness	Transverse strength, N/m^2	Permeability in air
A	1.6	40	27×10^6	2×10^{-2} Darcies
B	1.7	85	58	2×10^{-3} Darcies
C	1.85	90	69	2×10^{-4} Darcies
Vitreous	1.45	107	140	2.5×10^{-7} cm ² /sec (He)
Pyrolytic:				
Perpendicular	2.2	75	12 to 19×10^6	-----
Parallel	2.2	100	1.3	2×10^{-2} Darcies (He)

TABLE II. - COMPOSITION OF LIQUID
NATURAL GAS USED FOR
THESE STUDIES

[Source, NASA Mass Spectrometer.]

Hydrocarbon	Percent
CH ₄	93.2
C ₂ H ₆	4.7
C ₃ H ₈	.2
N ₂	1.8
C ₄ H ₁₀	.08
C ₅ H ₁₂	.08
O ₂	.02
Ar	↓
CO ₂	
H ₂	

purged with gaseous nitrogen (to atmospheric pressure). Metal rider specimens were ground to 10^{-1} micrometer rms (4 μ in. rms) and cleaned by the same procedure as for the metal disks. The materials used in this investigation are described in table I; an analysis of the liquid natural gas is shown in table II.

RESULTS AND DISCUSSION

Unlubricated Metals

Two rolling-element bearing steels (440C and 52100) and a cryogenic construction metal (304 steel) were studied in sliding contact submerged in liquid natural gas. All three metals (no lubricant supplied) were run using the same material for the rider and the disk.

The friction and wear results shown in figure 2 indicate that LNG does not lubricate these materials. Note the high friction coefficient obtained for all three metal combinations. If the curve of friction coefficient against molecular weight for steel on steel (fig. 2 of ref. 6) is extrapolated to 16 (molecular weight of CH₄) a friction coefficient of

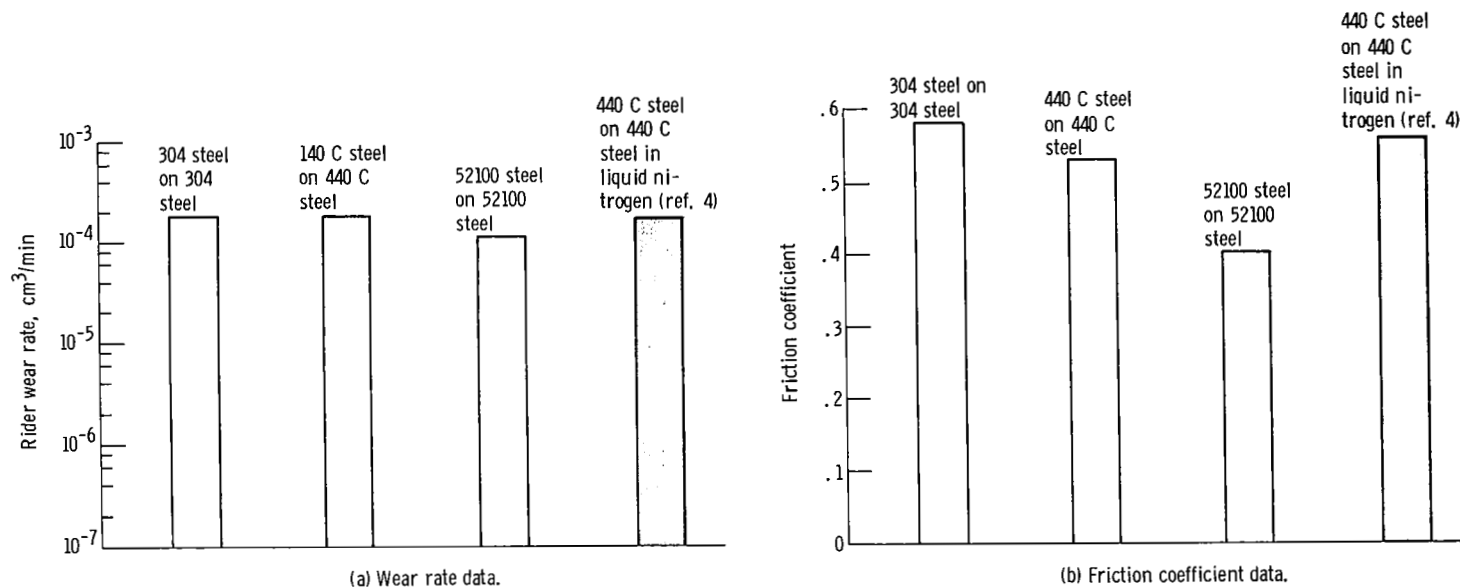


Figure 2. - Metal combinations sliding in liquid natural gas. Sliding velocity, 12.4 meters per second; load, 1 kilogram; duration, 30 minutes.

about 0.56 is obtained (for room temperature). That value is close to that obtained for the unlubricated metals combinations used in LNG.

In addition to the LNG data, figure 2 includes, for reference, the friction and wear of 440C steel sliding on 440C steel in liquid hydrogen (ref. 4). The results obtained for 440C steel in LNG are similar to those obtained for 440C steel in liquid hydrogen. Liquid hydrogen results are compared with LNG results because liquid hydrogen is not considered a boundary lubricant (refs. 3 to 5). The results obtained for 304 against 304 and 52100 against 52100 in liquid hydrogen were also similar to the results obtained for these metals in LNG. It is apparent that the higher temperature of LNG (measured boiling point, 112 K; as compared with the liquid hydrogen boiling point of 4.2 K) did not improve the friction and wear of these metal combinations. This indicates that the friction coefficient is more a function of the molecular weight of the environment than it is a function of the temperature of the environment.

Limited experiments with 440C steel and with 304 steel in 99.5 percent liquid methane, show essentially the same results as those obtained in LNG. These results are also similar to those obtained in liquid argon (unreported), liquid nitrogen (ref. 2), and liquid hydrogen (ref. 4).

Figure 3(a) shows photographs of the wear surfaces of the 440C steel on 440C steel specimens after running in LNG; the high wear and severe galling is shown.

Since it has been reported that frictional polymer is formed when metals (or non-metals) are in relative motion in hydrocarbon environment (ref. 9), it was expected that frictional polymer would be formed in these experiments. Examination of the wear surfaces shows no organic deposit, although it is possible that a frictional polymer was formed but was removed as rapidly as it was formed owing to the high sliding velocity used for these experiments.

Mechanical Carbons

Many dynamic seals for liquid nitrogen and liquid hydrogen use mechanical carbon as a component material. A problem found with carbons used for seals in these liquids (as well as in high-altitude generator brushes) is dusting. If the carbon does not form a tenacious oriented transfer film of graphite on the mating surface, it will dust or wear very rapidly. A method used to eliminate dusting of aircraft brushes is to treat the carbon with metal halides (e.g., BaF_2 (ref. 10)). This treatment has also been shown to be beneficial for carbons sliding in liquid nitrogen and in liquid hydrogen (ref. 3).

If a carbon is run in sliding contact in an environment containing moisture, oxygen, and/or hydrocarbon vapors, a graphite transfer film easily forms (ref. 6), and this film reduces the wear rate significantly. Similar results are obtained in liquid oxygen

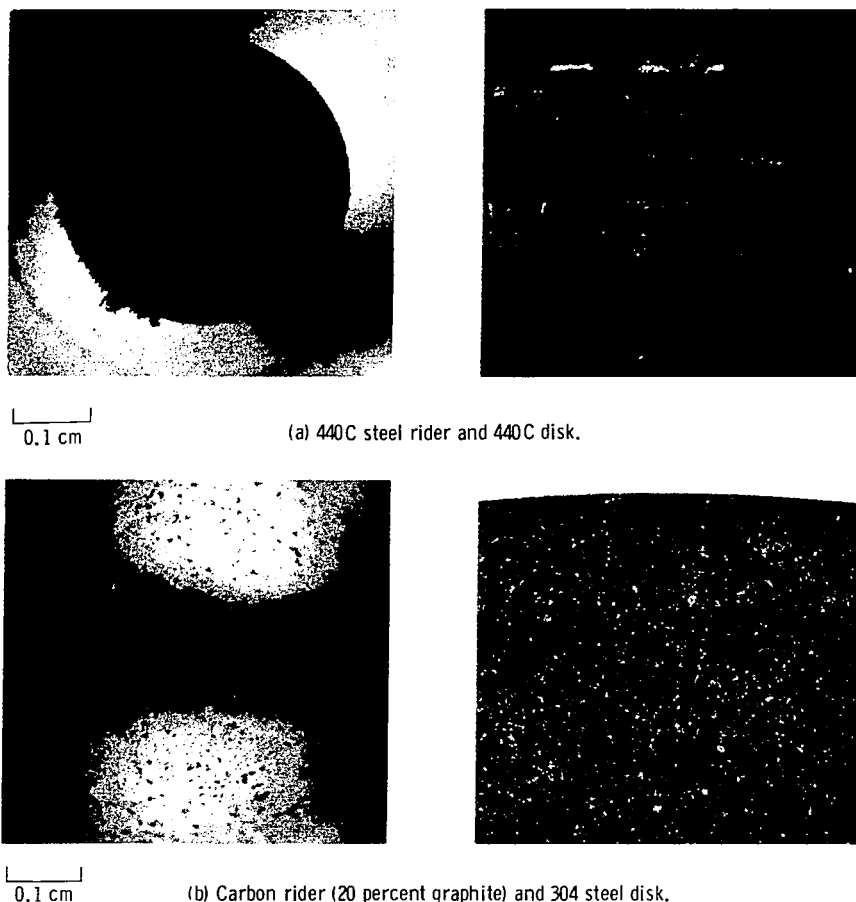


Figure 3. - Rider wear scars and disk wear tracks of two material combinations after sliding in liquid natural gas. Sliding velocity, 12.4 meters per second; load, 1 kilogram; duration, 30 minutes.

(ref. 11). If carbon is used in a vacuum environment, the adsorbed vapors in carbon are desorbed, and the wear rate is very high (ref. 6). Since LNG is a hydrocarbon mixture (see table II), the wear rate of carbon should be less than that obtained in liquid nitrogen or in liquid hydrogen.

The wear rate obtained with a 20-percent graphite (80 percent carbon) grade mechanical carbon when sliding against 304 steel in LNG is shown in figure 4(a). A comparison of the data obtained with the 20-percent graphite in LNG and in liquid nitrogen (reference) shows that the hydrocarbon environment (LNG) reduces the wear rate by a factor of more than 100. The friction coefficient (fig. 4(b)) was 0.15 in LNG and 0.2 in liquid nitrogen. Figure 3(b) shows photographs of typical wear surfaces after a 30-minute run. Note the thin transfer film on the disk and the smooth rider wear scar.

Another grade of carbon that was run in LNG was a 100-percent graphite material. The wear rate of this graphite (fig. 4(a)) was about 100 times as high as the wear of the

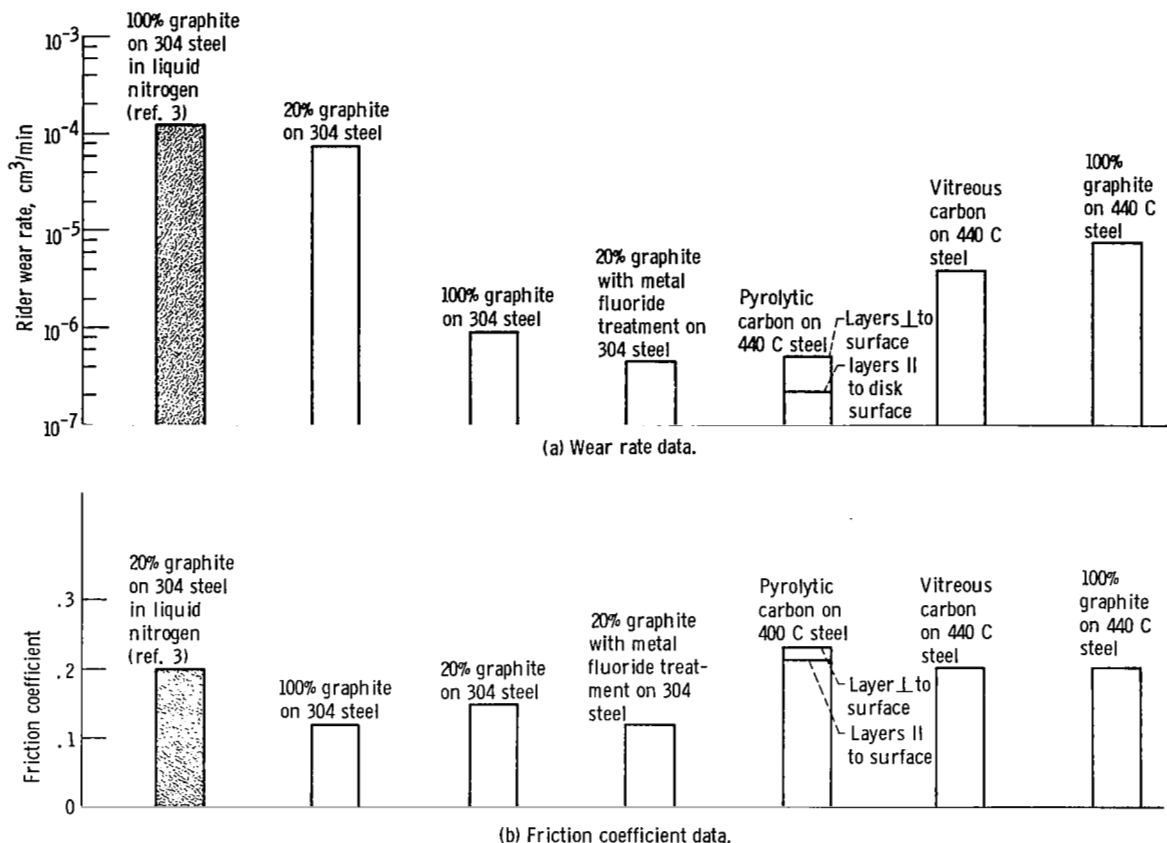


Figure 4. - Carbon sliding against steel in liquid natural gas. Sliding velocity, 12.4 meters per second; load, 1 kilogram; duration, 30 minutes.

20-percent graphite grade. The wear rate of the 100-percent graphite grade in LNG was, however, 1000 times less than that obtained in liquid nitrogen (unreported). This result shows the influence of the hydrocarbons of LNG on the wear rate. Note that the wear rate is higher for higher graphite content. This is the reverse effect that was noted in liquid oxygen (ref. 11).

Also of importance to the wear (and friction) of carbon is the mating surface. Figure 4(a) shows that the wear rate of the 100-percent graphite grade carbon is reduced by a factor of 10 if the mating surface is 440C steel instead of 304 steel. The linear variable differential transformer (LVDT) showed that the initial high wear rate continued for a longer time period when the carbon was running against 304 steel than when running against 440C steel. This indicated that the graphite transfer film was more difficult to form on the 304 steel, thus increasing the total wear. The friction coefficient (fig. 4(b)) is approximately twice as high (0.20 against 0.12) when the 100-percent graphite is run against 440C steel instead of 304 steel. The lower friction coefficient reported for the

carbon on 304 steel is a result of the accumulated wear debris in the test chamber and of the larger contact area of the rider (the initial friction coefficient was 0.25).

Treating the 20-percent graphite with a metal fluoride showed no significant improvement in wear rate in LNG, whereas the same treatment reduced the wear rate by a factor of 100 in liquid nitrogen (ref. 1).

Pyrolytic carbon was run with the carbon strata or layers perpendicular (I) and also parallel (II) to the direction of sliding. Pyrolytic carbon was run against 440C steel disk instead of the softer 304 steel disk to minimize the surface damage to the disk by this harder carbon. Figures 4(a) and (b) show the effect of anisotropy on friction and wear rate. When the rider was run with the strata parallel to the disk, the rider wear was higher and the friction coefficient was lower than that with the perpendicular direction. This effect was to be expected because this is the plane of easy shear. Wear with the parallel direction is $2\frac{1}{2}$ times as high as with the perpendicular orientation (fig. 4(a)).

As mentioned earlier, the wear of carbon materials is significantly affected by the vapors and liquids found in its operating environment (e.g., moisture, oxygen, and hydrocarbons). Carbon materials have relatively large surface areas (10 to 30 m²/g is common; 1000 m²/g is possible) and high permeability to gases, which increases its ability to adsorb vapors (or liquids) from its operating environment. These adsorbed vapors influence the formation of the transfer film (graphite film) on the mating surface and thus affect the wear rate of the carbon. As shown on figure 4(a), the wear rate in LNG is considerably less than the wear rate in liquid hydrogen (reference bar), which indicates the importance of the hydrocarbon vapors or liquids in reducing the wear rate of carbon. The highly polished wear scar (on the rider) also indicates that the sliding process is orienting the graphite platelets of the rider rather than just wearing away the carbon as is common in environments such as liquid nitrogen or liquid hydrogen. Also, the faint, smooth film on the disk is indicative of good lubrication by a carbon.

Vitreous (or glassy) carbon was included in this program because it has low permeability (ref. 12) and low surface area. The lower surface area should reduce the ability of vitreous carbon to adsorb vapor from its environment. Figure 4(a) shows that the wear of vitreous carbon is greater than the wear of pyrolytic carbon (the average of perpendicular and parallel wear rates) by a factor of about 4. Both the vitreous carbon and pyrolytic carbon were run against 440C steel and are therefore comparable. The lower than expected wear for vitreous carbon was probably a result of the higher hardness.

All the carbons except the vitreous carbon produced faint transfer films on the mating surface. The vitreous carbon did not produce a visible transfer film on the mating surface but rather appeared to have polished the metal disk. For comparison, carbon riders run in liquid nitrogen and in liquid hydrogen showed dense, dull transfer films on the mating disks.

Several experiments were conducted with the 20-percent graphite grade carbon in 99.5 percent liquid methane. Wear of the carbon was significantly greater in the liquid methane, which indicates that the higher molecular weight fractions of the LNG must be contributing to the wear reduction noted in LNG.

CONCLUDING REMARKS

1. Metal-metal combinations (440C stainless steel on 440C stainless steel, 52100 carbon steel on 52100 carbon steel, and 304 stainless steel on 304 stainless steel) were run in sliding contact in liquid natural gas. The high friction, wear, and the tendency to gall experienced with these combinations indicated that liquid natural gas does not provide lubrication when compared with the higher molecular weight hydrocarbons used at normal temperatures.

2. Experiments conducted with three grades of mechanical carbons indicated that liquid natural gas does reduce the wear rate below that of other cryogenic fluids such as liquid hydrogen or nitrogen. The wear rate of these mechanical carbons in liquid natural gas was less than 1 percent of that obtained in liquid hydrogen. The friction coefficient was not significantly affected by the hydrocarbon environment.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, September 21, 1971,
114-03.

REFERENCES

1. Eisenberg, Joseph D.; and Chambellan, Rene E.: Tankage Systems for a Methane Fueled Supersonic Transport. Paper 68-196, AIAA, Feb. 1968.
2. Wisander, D. W.; Hady, W. F.; and Johnson, R. L.: Friction Studies of Various Materials in Liquid Nitrogen. NACA TN 4211, 1958.
3. Wisander, D. W.; and Johnson, R. L.: Wear and Friction of Impregnated Carbon Seal Materials in Liquid Nitrogen and Hydrogen. Advances in Cryogenic Engineering. Vol. 6. K. D. Timmerhaus, ed., Plenum Press, Inc., 1961, pp. 210-218.
4. Wisander, D. W.: Lead, Indium, and Tin as Potential Lubricants in Liquid Hydrogen. NASA TN D-6455, 1971.

5. Wisander, D. W.; and Johnson, R. L.: Wear and Friction in Liquid Nitrogen and Hydrogen of the Materials Combinations Carbon-Stainless Steel and Carbon-Carbon. Presented at the 1960 Air Force - Navy - Industry Propulsion Systems Lubricants Conference, San Antonio, Texas, Nov. 15-17, 1960.
6. Hardy, Sir William B.: Collected Scientific Papers. Cambridge University Press, 1936, pp. 645-667.
7. Savage, Robert H.: Graphite Lubrication. J. Appl. Phys., vol. 19, no. 1, Jan. 1948, pp. 1-10.
8. Fullam, Ernest F.; and Savage, Robert H.: Carbon Film Formation and Commutator Brush Wear as Revealed by the Electron Microscope. J. Appl. Phys., vol. 19, no. 7, July 1948, pp. 654-661.
9. Hermance, H. W.; and Egan, T. F.: Organic Deposits on Precious Metal Contacts. Bell Syst. Tech. J., vol. 37, no. 3, May 1958, pp. 739-776.
10. Elsey, Howard M.: Treatment of High-Altitude Brushes by Application of Metallic Halides. Elec. Eng., vol. 64, no. 8, Aug. 1945, pp. 576-579.
11. Hady, William F.; Allen, Gordon P.; and Johnson, Robert L.: Wear and Friction of Mechanical Carbons in Liquid Oxygen as Influenced by Transfer Films. ASLE Trans., vol. 6, no. 3, July 1963, pp. 201-208.
12. Cowlard, F. C.; and Lewis, J. C.: Vitreous Carbon - A New Form of Carbon. J. Mat. Sci., vol. 2, no. 6, Nov. 1967, pp. 507-512.